SPICE Overview

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The SPICE system has been developed by the California Institute of Technology, under contract with the National Aeronautics and Space Administration

Space Science Data: Two Kinds

Science Instrument Data
including calibration data

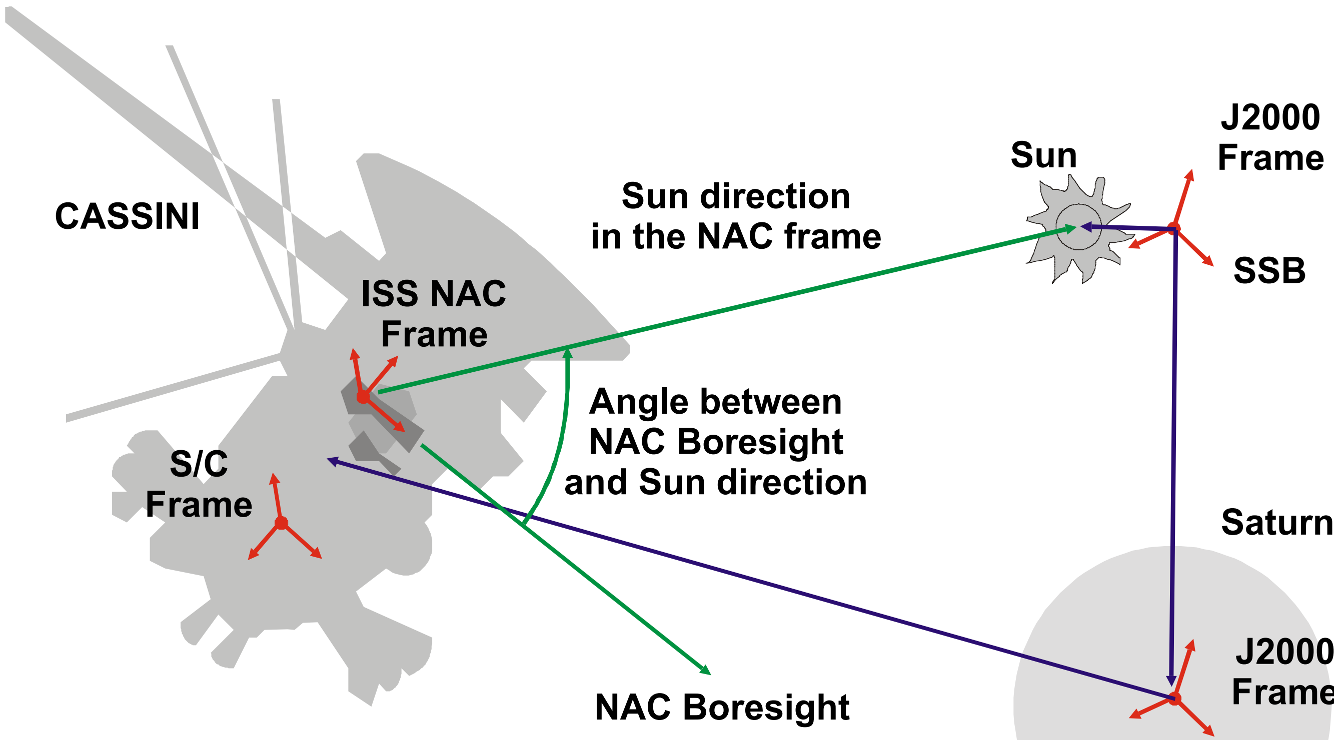
Ancillary or Engineering Data

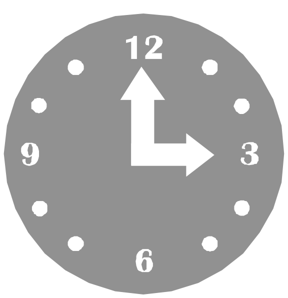
SPICE deals with <u>these</u> data

- **Some from the spacecraft**
- **Some from the mission control center**
- **Some from the spacecraft and instrument builders**
- **Some from scientists**

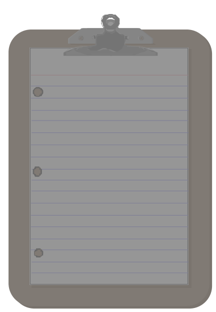
The Subjects of SPICE

SPICE Deals with Observation Geometry, Time and Events

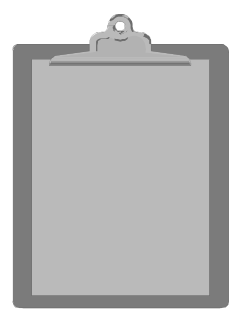




SCLK or SCET

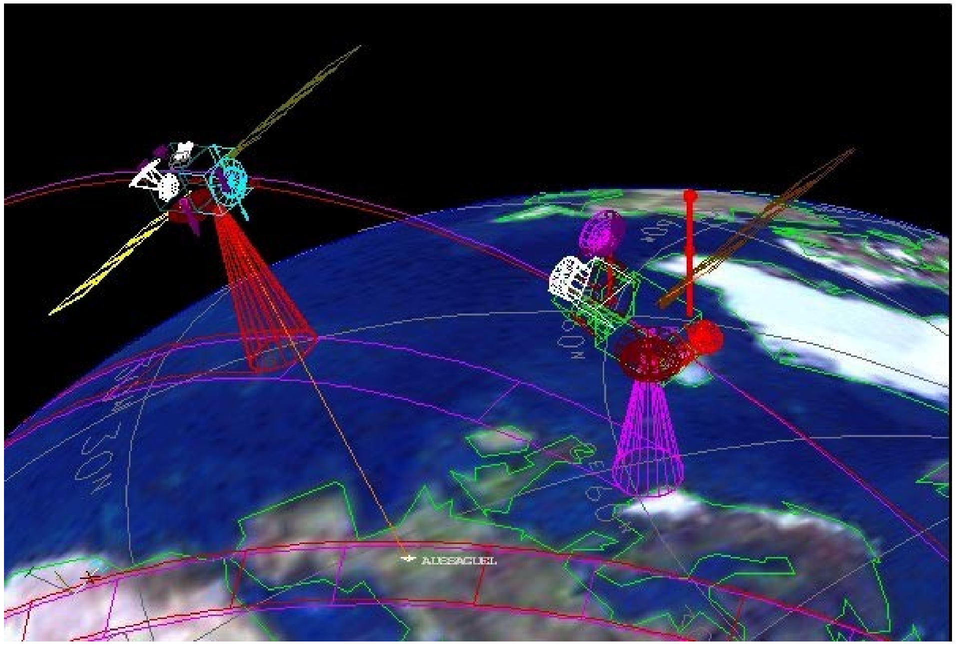


Today's Plan of Observations



Yesterday's Log of Events

Why SPICE?



Knowing observation geometry and events is an important element in the design of space missions and in the analysis of the science data returned from the instruments.

Having standard methods for producing and using ancillary data reduces cost and risk, and can help scientists achieve more meaningful and accurate results.

What are “Ancillary Data”?

- “Ancillary data” are those that help scientists and engineers determine:
  - when and how an instrument was acquiring data
  - where the spacecraft was located
  - how the spacecraft and its instruments were oriented (pointed)
  - what was the location, size, shape and orientation of the target being observed
  - what other relevant events were occurring on the spacecraft or ground that might affect interpretation of:
    - science observations
    - spacecraft systems performance

SPICE System Components

- The principal SPICE system components are two
  - Data files, often called “kernels” or “kernel files”
  - Software, known as the SPICE Toolkit
    - This software is, in general, not an executable program
- Also part of SPICE are:
  - standards
  - documentation
  - customer support
  - system maintenance and continuing development

Genesis of the SPICE Acronym*

S	**S**pacecraft
P	**P**lanet
I	**I**nstrument
C	**C**-matrix (spacecraft attitude)
E	**E**vents

*** Coined by Dr. Hugh Kieffer, USGS Astrogeology Branch, Flagstaff AZ**

Logical versus Physical View

Logical View	Physical View	
S Spacecraft	**SPK**	Spacecraft, orbiter, rover or natural body trajectory
P Planet	**PcK**	Target body (e.g. Mars) size, shape and orientation
I Instrument	**IK**	Instrument field-of-view geometry
C C-matrix	**CK**	Orientation of spacecraft or rover or any articulating structure
E Events	**EK** ESP ESQ ENB	Events information: - Science Plan (ESP) - Sequence of events (ESQ) - Experimenter's Notebook (ENB)
	Others: **FK**	Reference Frame specifications
	Others: **LSK**	Leapseconds
	Others: **SCLK**	Spacecraft clock coefficients
S Software	**SPICE Toolkit**	FORTRAN and C module libraries, plus a few utilities and applications

= "fixed" data (green)

= time varying data (blue)

SPICE System Contents - 1

SPK

- Space vehicle ephemeris (trajectory)
- Planet, satellite, comet and asteroid ephemerides
- More generally, position of something relative to something else

PcK

- Planet, satellite, comet and asteroid orientations, sizes, shapes
- Possibly other similar "constants" such as parameters for gravitational model, atmospheric model or rings model

IK

- Instrument information such as:
  - Field-of-View specifications
  - Internal timing

SPICE System Contents - 2

CK

- **Instrument platform attitude**
- **More generally, orientation of something relative to a specified reference frame**

EK
3 components

- **"Events," broken into three components:**
  - **ESP: Science observation plans**
  - **ESQ: Spacecraft & instrument commands**
  - **ENB: Spacecraft "notebooks" and ground data system logs**

SPICE System Contents - 3

FK

- **Frames Definitions**
  - **Definitions of and specification of relationships between reference frames (coordinate systems)**

LSK

- **Leapseconds Tabulation**
  - **Used for UTC <--> ET time conversions**

SCLK

- **Spacecraft Clock Coefficients**
  - **Used for SCLK <--> ET time conversions**

Other Kernels

- **Mission (mappings between names and ID codes)**
- **Star (sky) catalog***
- **Shape model for small, irregular bodies***
- **Terrain***
- **Control net***

* = under development

UTC = Universal Time Coordinated **ET = Ephemeris Time** **SCLK = Spacecraft Clock Time**

SPICE System Contents - 4

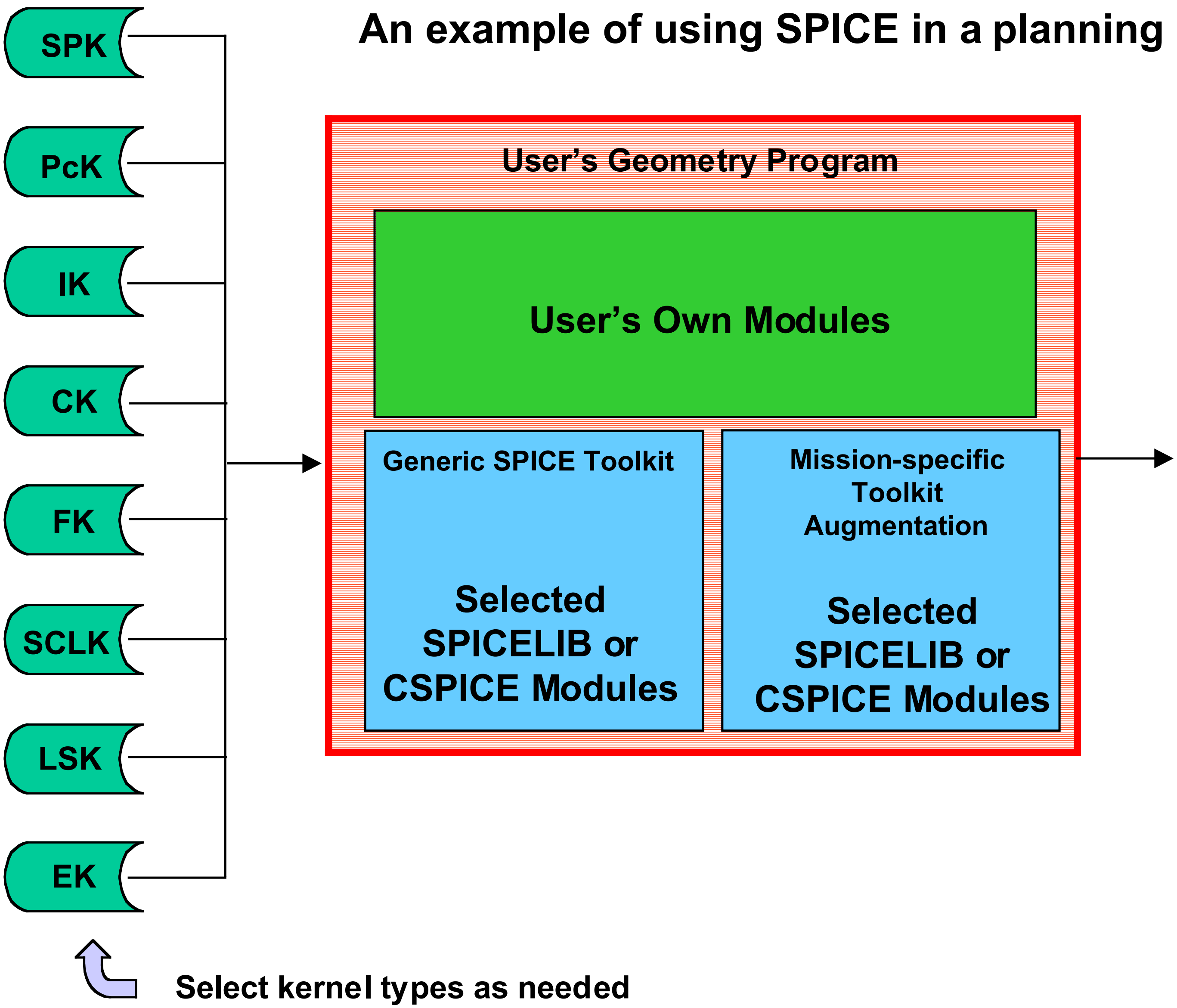
SPICE Toolkit

FORTRAN C-language

- SPICELIB or CSPICE subroutine library, used to:
  - write binary SPICE kernel files
  - read all (binary and text) SPICE kernel files
  - compute quantities derived from SPICE kernel data
- Example ("cookbook") programs
- Utility programs
  - Kernel summarization or characterization
  - Kernel management
- Application programs (a few)
  - e.g. "chronos" time conversion application
- Kernel production programs (a few)
  - e.g. "mkspk" trajectory generator
- An IDLSPICE Toolkit is being developed

Using SPICE Library Modules

An example of using SPICE in a planning activity



- Instrument pointing plan

  or

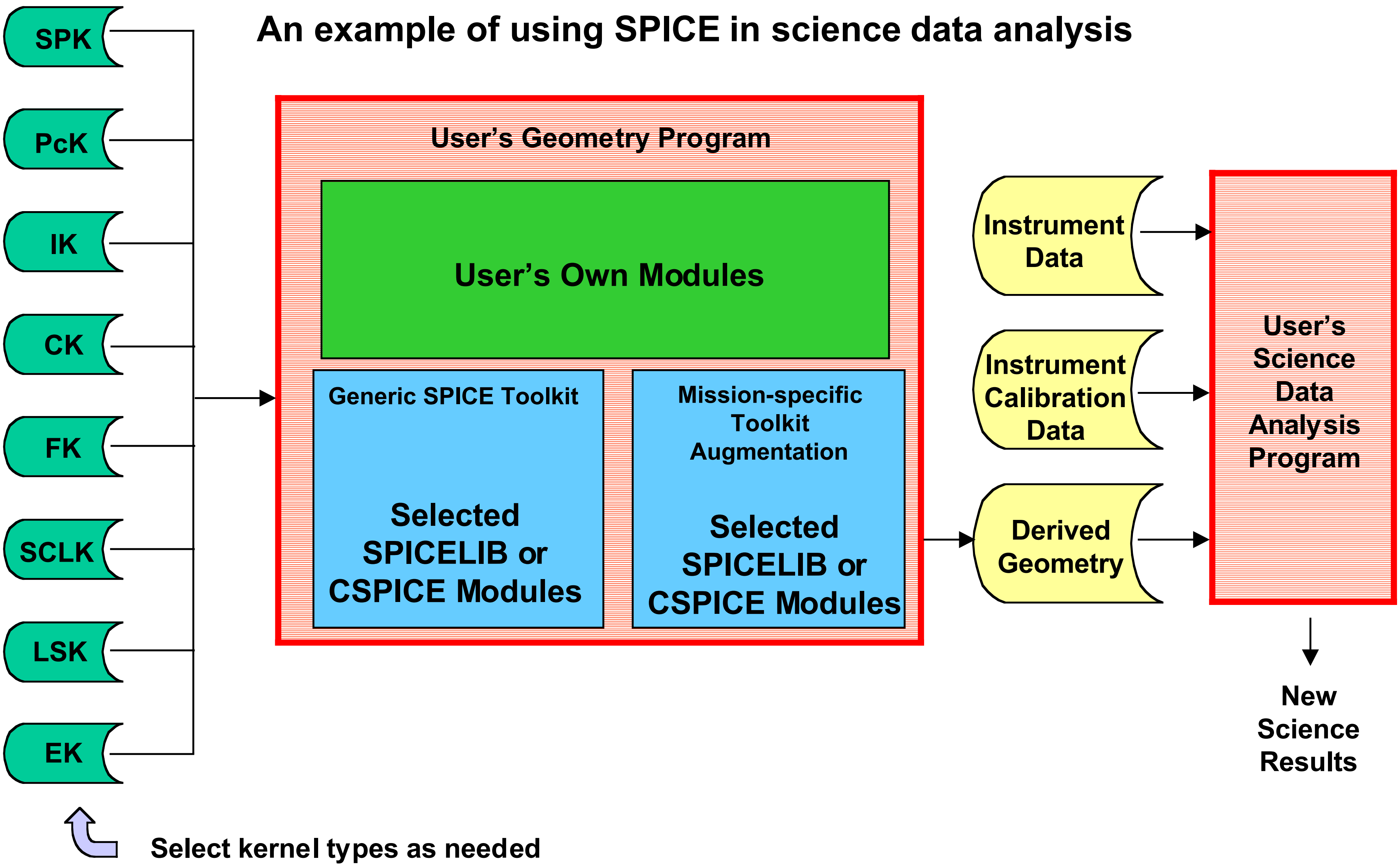
- Observation geometry visualization

  or

- Results of a search for some desired geometric conditions

Using SPICE Library Modules

An example of using SPICE in science data analysis



SPICE System Characteristics - 1

- Portable SPICE kernel files
- Portable SPICE Toolkit software
  - Already ported to and tested on most popular platforms
    - PC/Win, PC/Linux, Mac, Sun, SGI, HP, Alpha, VAX
- Focus is on the customer
  - Code is well tested before being released to users
  - Once released, code functionality is never changed or removed
    - Except NAIF does reserve the right to fix bugs
  - Extensive, clear documentation is provided
    - Includes well documented source code, provided to each user
  - The SPICE Toolkit contains some example (“cookbook”) programs
  - An extensive set of SPICE tutorials is available

SPICE System Characteristics - 2

- All computations are double precision
- System includes built-in exception handling
  - Trace back , configurable action upon detection of an exception
- Has access to all of JPL's latest integrated ephemerides for spacecraft and natural bodies (planets, satellites, comets, asteroids)
- Kernel files are separable
  - Use only those you need for a particular application
- Kernel files are extensible
  - New data "types" can be added within a family
  - New kinds of kernels can be defined
- Broad applicability and good value
  - Multimission and multidiscipline (see list of major projects)
  - SPICE development and maintenance costs are shared across many customers

SPICE System Characteristics - 3

- The generic SPICE Toolkit is generally free to individual users
  - Core SPICE system development is funded by NASA's Office of Space Science
  - NASA flight projects fund NAIF to adapt and deploy SPICE in support of NASA missions, and for some cooperative missions
    - E.g. Clementine, Huygens Probe, Mars Express, … possibly Rosetta
  - NASA provides consultation and some tools for agencies using SPICE SPK files to schedule Deep Space Network stations
- Very few restrictions on distribution and use of SPICE software and SPICE files
  - Note: SPICE software is copyrighted © by the California Institute of Technology

For What Jobs is SPICE Used ?

Increasing mission maturity (time)

- Mission planning, modeling and visualization
- Pre-flight mission evaluation from a science perspective
- Detailed science observation planning
- Mission operations engineering functions
- Science data analysis, including correlation of results between instruments, and with data obtained from other missions
- Data archiving, for future use by others

The original focus of SPICE

- Education and Public outreach

What Vehicle Types Can Be Supported ?

- Cruise/Flyby
  - Remote sensing
  - In-situ measurement
  - Instrument calibration
- Orbiters
  - Remote sensing
  - In-situ measurement
  - Communications relay
- Landers
  - Remote sensing
  - In-situ measurements
  - Surface analysis
  - Rover or balloon relay
- Rovers
  - Remote sensing
  - In-situ sensing
  - Local terrain characterization
- Balloons*
  - Remote sensing
  - In-situ measurements

* Not yet demonstrated

Major SPICE Customers

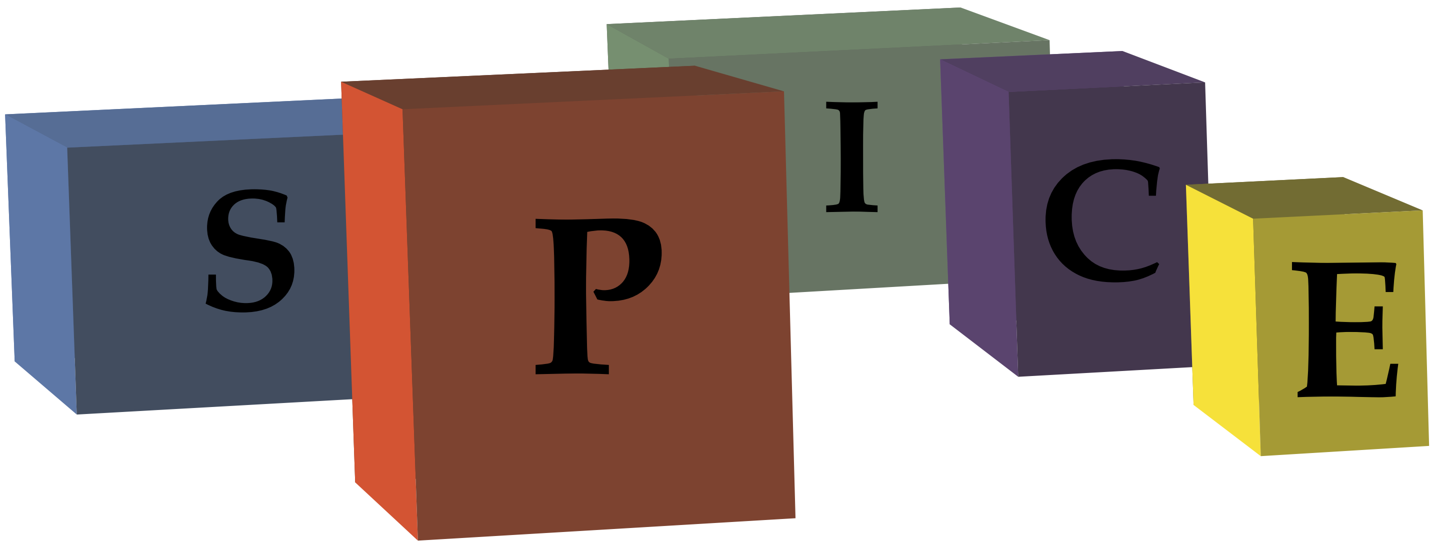
Restorations	Past Customers	Current Customers	Future Possibilities
Apollo 15, 16 [P]	Magellan [P]	Galileo	Mars 07, 09, …
Mariner 9 [P]	Clementine (NRL)	NEAR	Nozomi (Japan)
Mariner 10 [P]	Mars Observer	Mars Global Surveyor	Messenger
Viking Orbiters [P]	Mars 96 (Russia)	Stardust	Starlight
Pioner 10/11 [P]	Hubble Telescope [S]	Cassini/Huygens	Rosetta (ESA)
Haley armada [P]	ISO [S]	Deep Space 1	BepiColombo (ESA)
Phobos 2 [P] (Russia)	MSTI-3 (by ACT Corp.)	Mars Odyssey	Europa Orbiter
Ulysses [P]	OTD (by MSFC)	Mars Exploration Rover	Pluto
Voyagers [P]	Mars Pathfinder	SIRTF [S]	Space Interferometry
	Mars Climate Orbiter	Genesis	
	Mars Polar Lander	Mars Express (ESA)	
	Space VLBI [P]	DSN Metric Predicts [S]	
		Deep Impact	
		CONTOUR	
		Mars Recon. Orbiter	

[P] = partial use of SPICE

[S] = special tools or services provided by NAIF

Building Blocks for Your Applications

NASA offers its “SPICE” ancillary information system as a model and core set of blocks for building tools that can help execute a multimission, international space exploration program



Examples - 1
What Can You Do With SPICE ?

- Mission Design
  - Compute all interesting orbit properties; compare these with those of another design, or with another mission
  - Evaluate possibilities for relay link times and duration

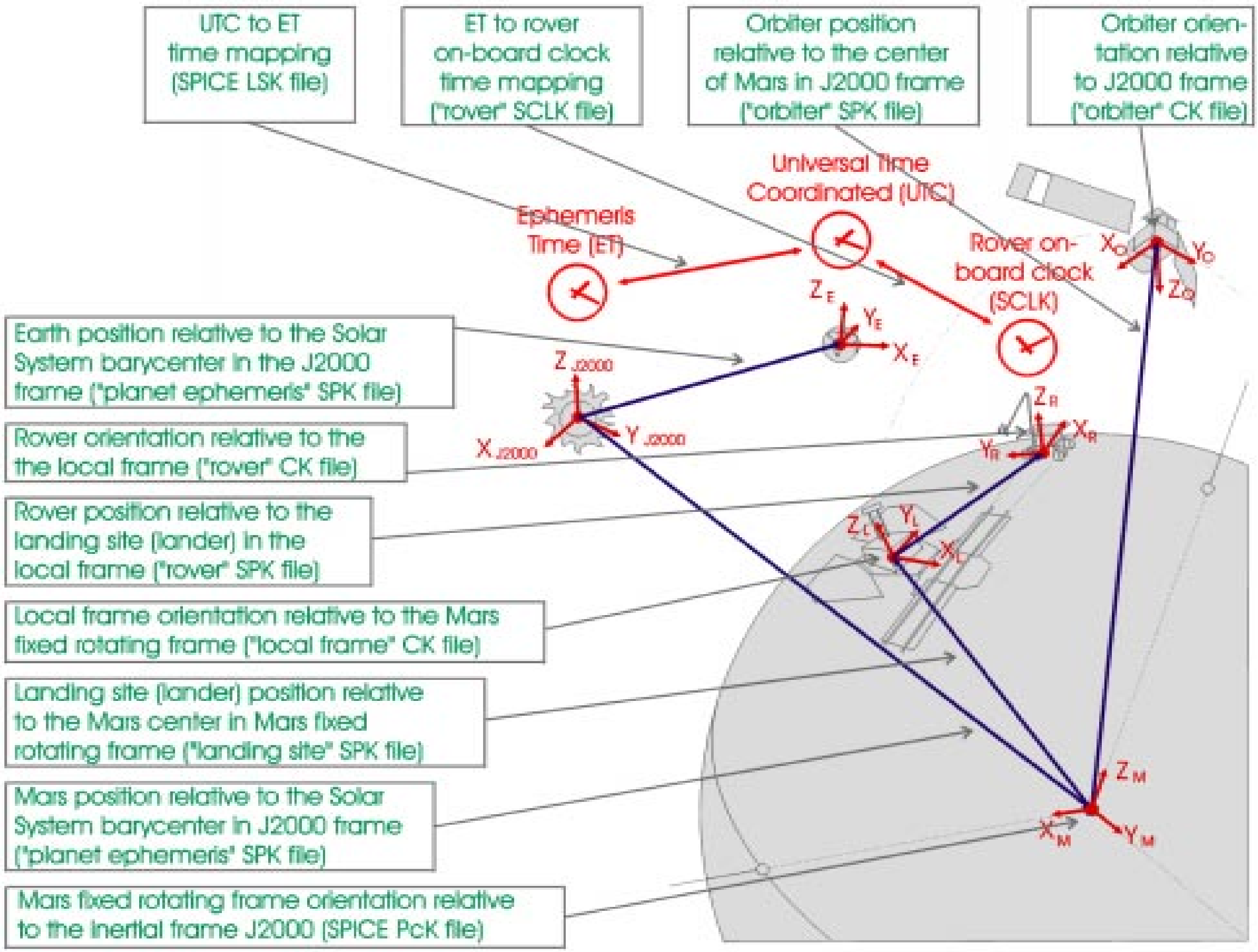
- Science
  - Compute footprint coverage over time; compare against those from another instrument on your spacecraft or on a different spacecraft
  - Design specific observations to be acquired
  - Compute observation geometry needed to analyze your data, such as:
    - Lighting angles
    - Location (LAT/LON) of instrument footprint
    - Range and local time

Examples - 2
What Can You Do With SPICE ?

- Mission Operations
  - Predict or evaluate telecommunications link performance
  - Analyze spacecraft orientation history
  - Determine elevation and rise/set times of sun and tracking stations
  - Compute location of a long range rover or a balloon

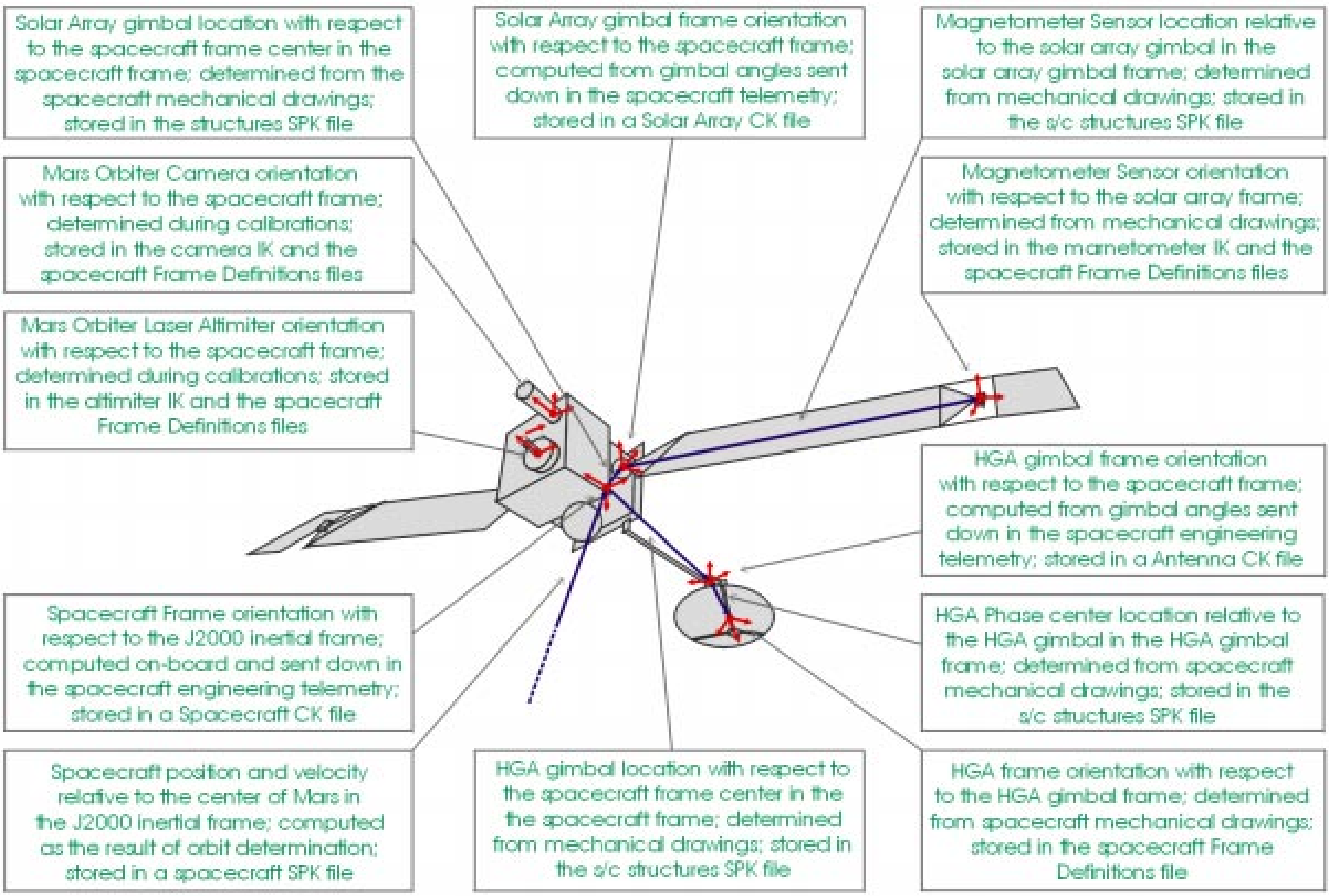
- Visualization, Education and Public Outreach
  - Provide geometry used to drive web pages giving interesting parameters such as ranges, velocities, time of day on Mars
  - Provide geometry for animations showing orbiter location and orientation, instrument footprint projected on the surface, and locations of surface assets or natural features of interest
  - Help get upper class students involved in space mission design

Global SPICE Geometry



Applying SPICE to a Full Planetary Investigation: Orbiter, Lander, Rover

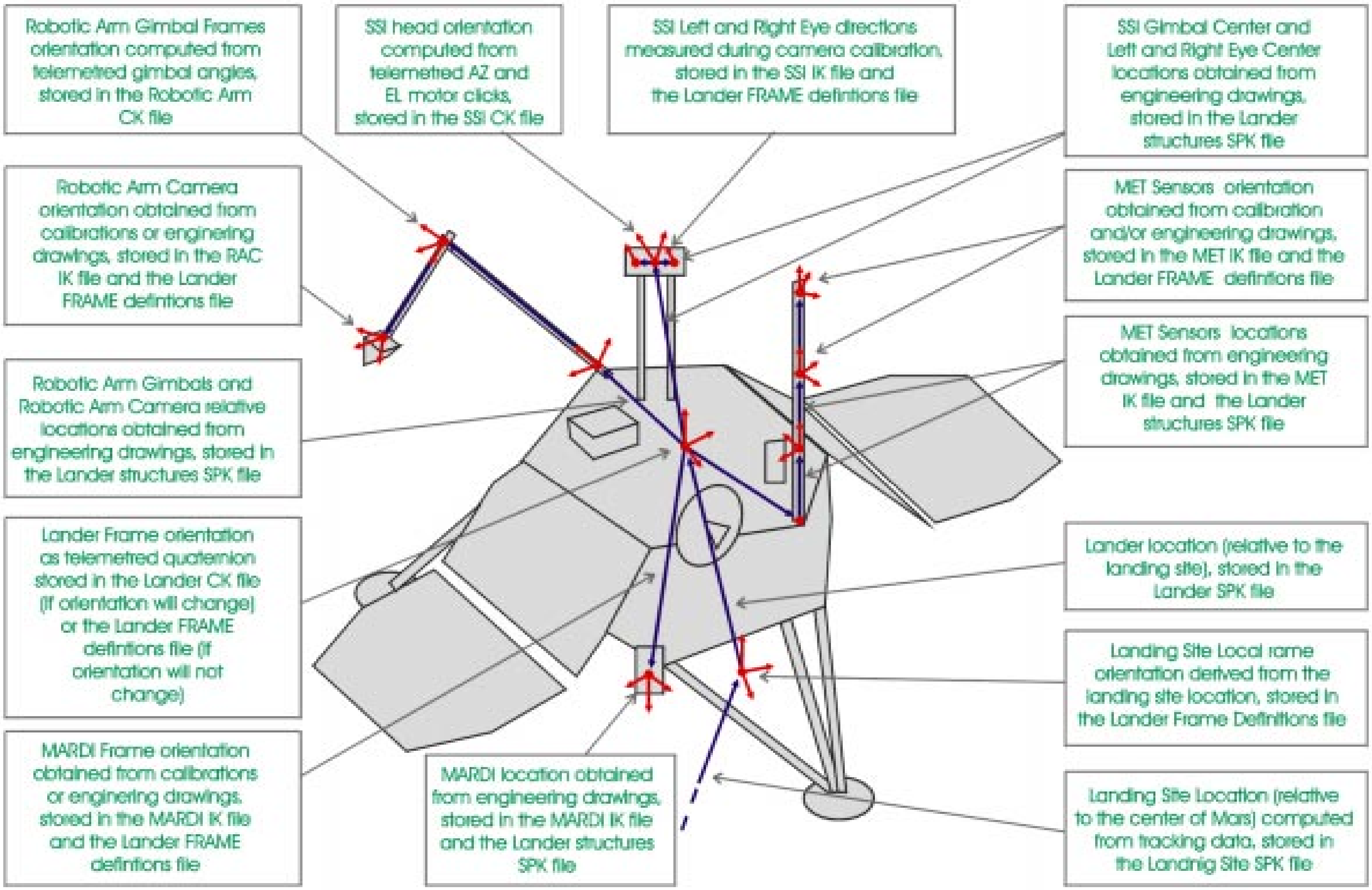
Orbiter Geometry



Applying SPICE to an Orbiter (MGS)

Lander Geometry

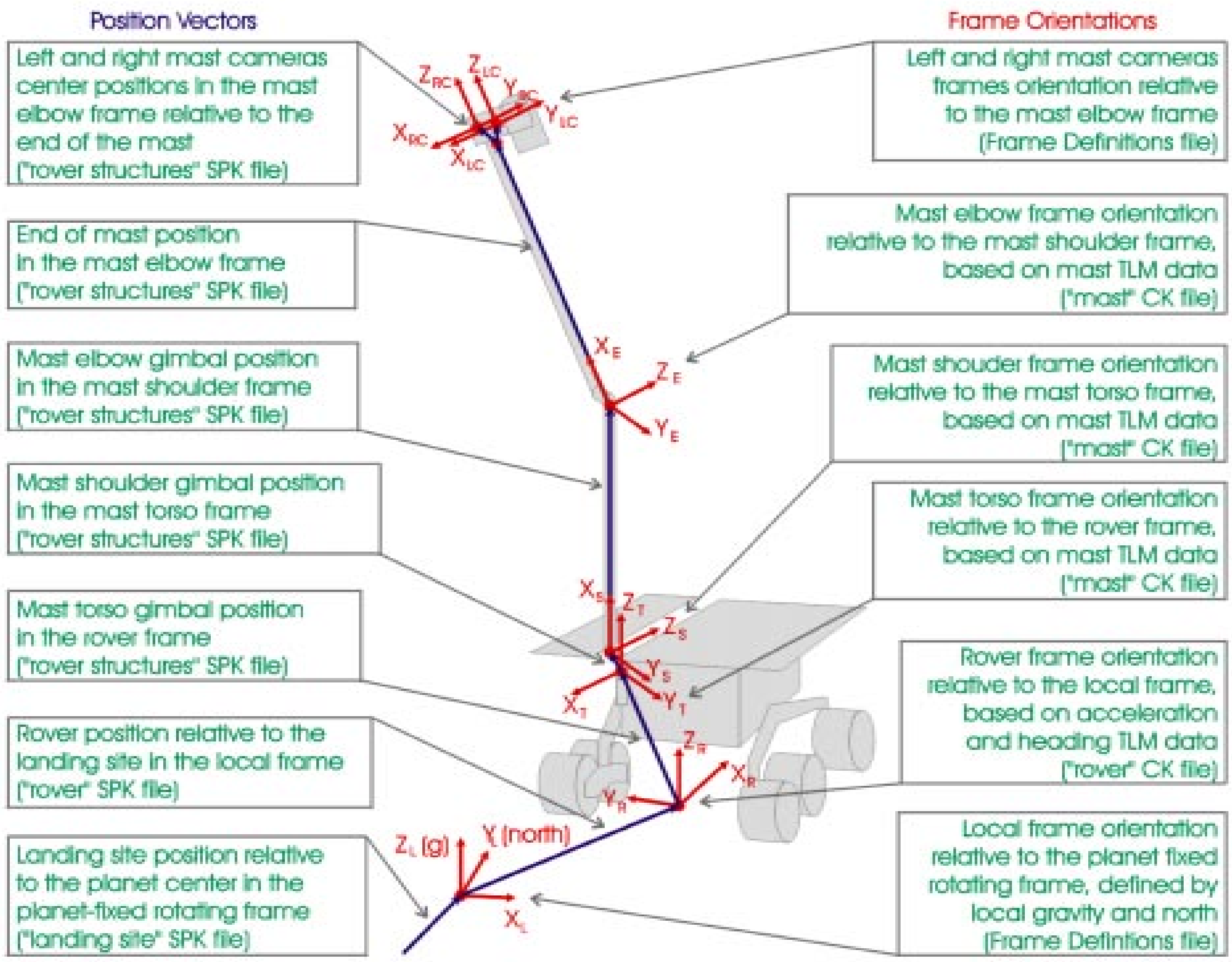
Navigation and Ancillary Information Facility - JPL



Applying SPICE to a Lander (M98)

Rover Geometry

Navigation and Ancillary Information Facility - JPL



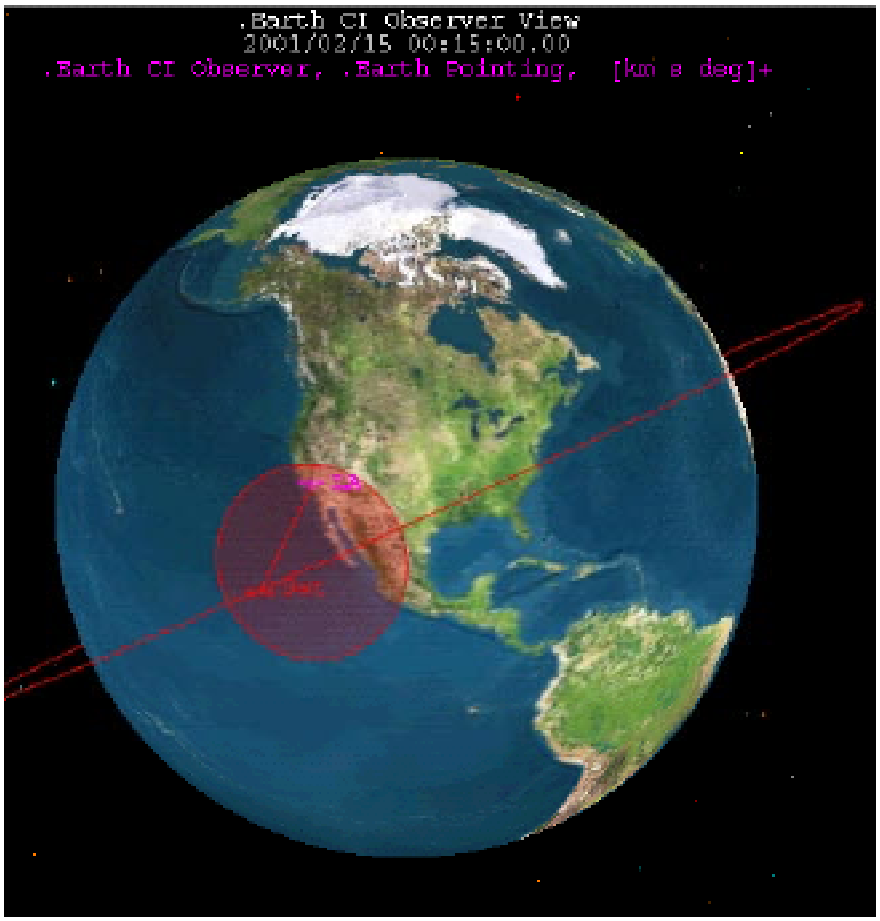
Applying SPICE to a Surface Rover (Rocky-7)

A Few Examples of SPICE-Based Applications

Convey Trajectory Design

- Trajectory design tools can produce output ephemerides in the SPICE SPK format, for easy use in other analysis and visualization tools in the overall mission design process

Visualization Tools

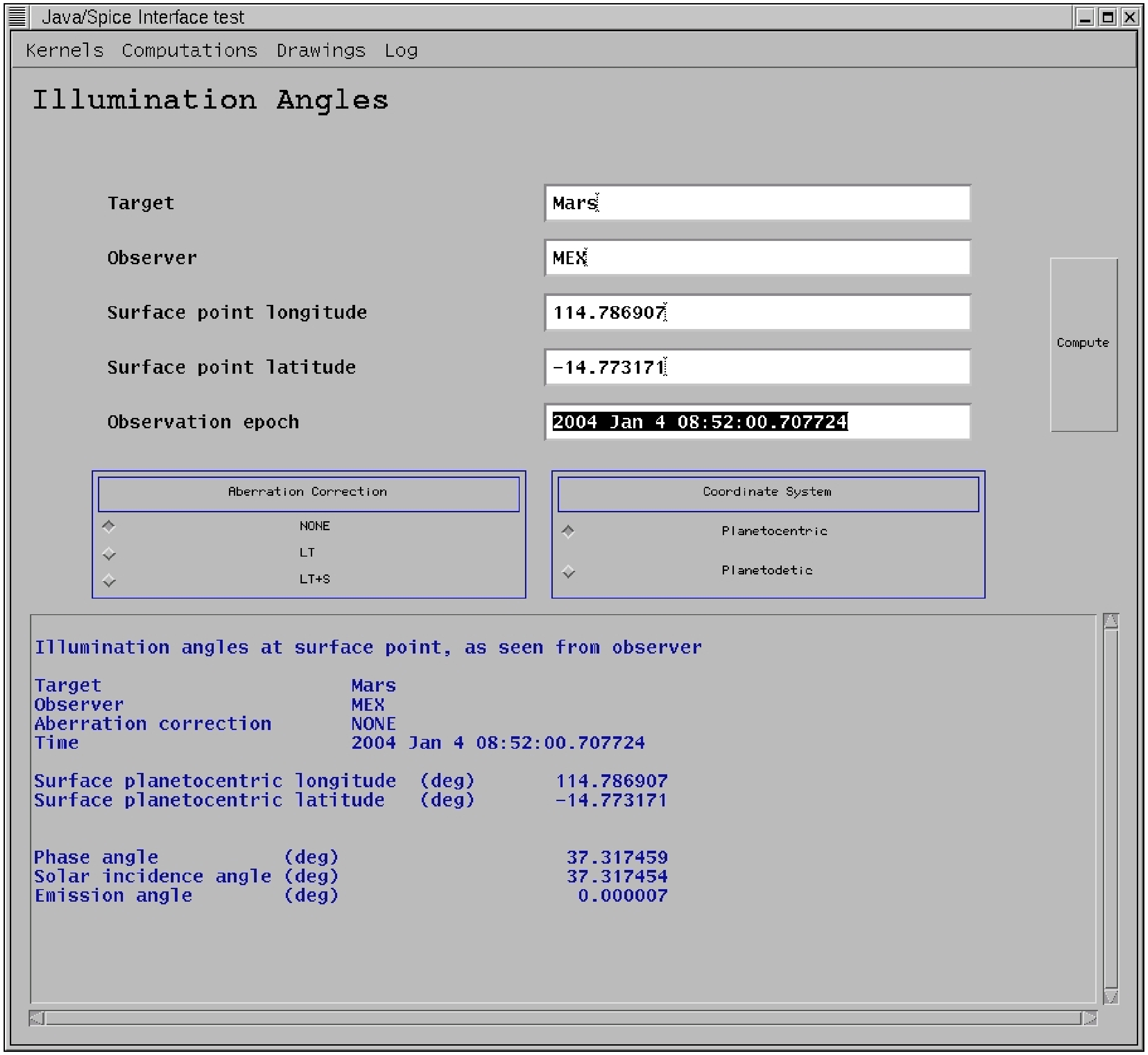


- Satellite Tool Kit (STK) ©
  - Analytical Graphics Inc.
    (Uses only SPK files)
- Satellite Orbit Analysis Program (SOAP) ©
  - Aerospace Corporation
- Pointing Design Tool (PDT)
  - JPL
- Science Opportunity Analyzer (SOA)
  - JPL
- Mars Express Science SOA (MEXSOA)
  - DLR, Inst. for Planetary Exploration
- Micro-Helm
  - JPL
- Cassini Pointing Designer (CASPER)
  - Univ. of Colorado
- Interactive Data Language (IDL) ©
  - Research Systems Inc.
    (Using SPICE “wrappers” around CSPICE modules)

Data Processing Tools

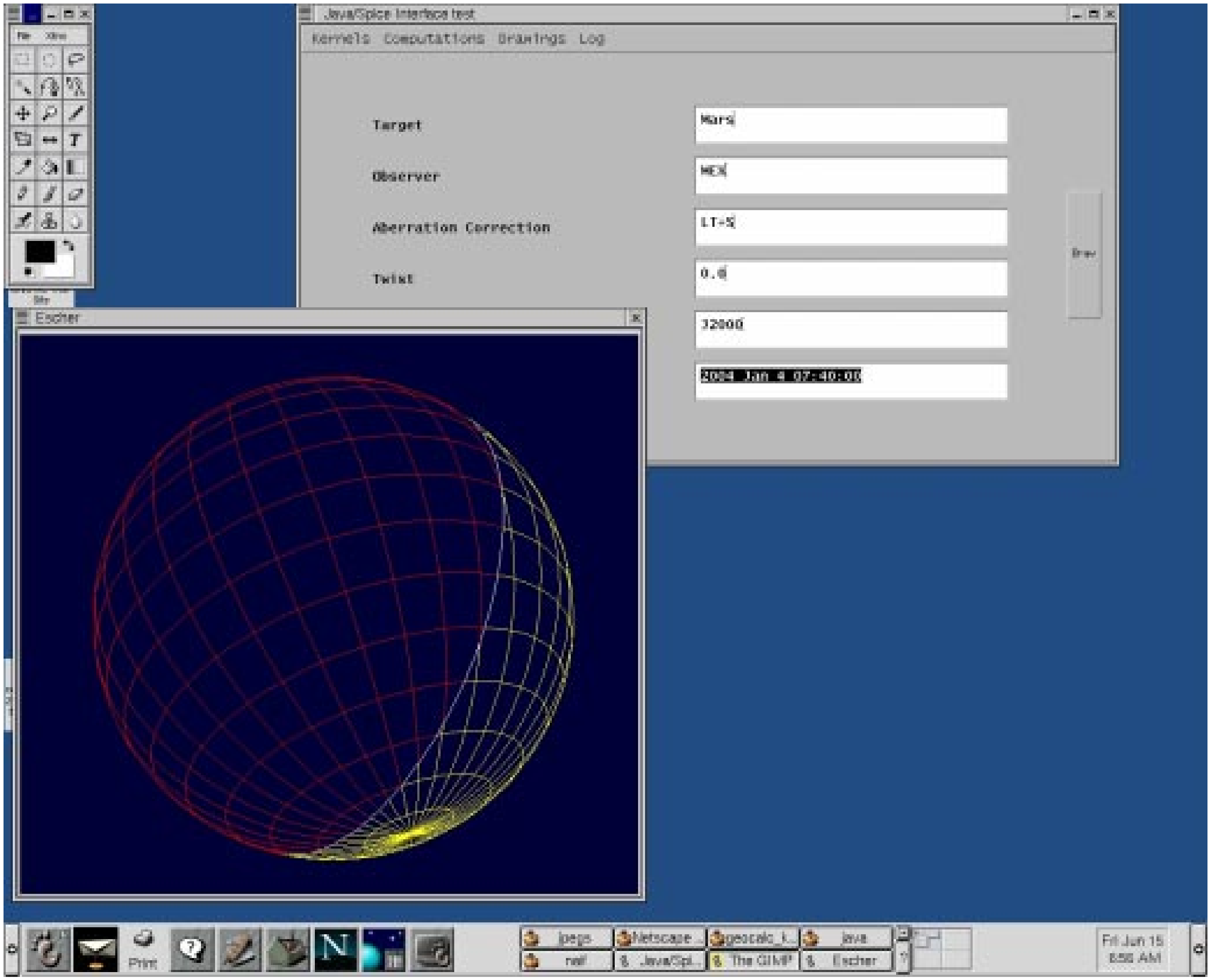
- Numerous science teams have developed their own observation planning and data processing software systems which obtain needed observation geometry using SPICE files and allied SPICE Toolkit modules
- Engineering teams have built analysis tools which obtain needed observation geometry using SPICE files and allied SPICE Toolkit modules
  - Examples: telecommunications and thermal analysis

GEOCALC
A Simple, Limited Geometry Calculator



Compute the phase, solar incidence and emission angles at some surface point on a target as seen from an observer at some epoch.

In this example, compute the illumination angles on Mars at LON 114.7 and LAT -14.7 as seen from Mars Express on 2004 JAN 4 08:52:00. Can pick either planetocentric or planetodetic frame.



Draw the appearance of a target as seen from an observer at some epoch.

In this example, draw the appearance of Mars as seen from Mars Express on 2004 JAN 4 07:40:00.

Supported Platforms - 1

- The SPICE Toolkit has been ported to a wide variety of popular platforms
  - Each platform is characterized by
    - Hardware type
    - Operating System
    - Compiler
    - Selected compilation options
- NAIF provides separate SPICE Toolkit packages for each supported platform

Supported Platforms - 2

Hardware	Operating System	Fortran Compiler / Options	C Compiler / Options
DEC Alpha	Alpha Digital Unix	Digital Fortran	Digital C
DEC Alpha	Open VMS	Digital Fortran, DFLOAT	N/A
DEC Alpha	Open VMS	Digital Fortran, GFLOAT	N/A
DEC VAX	VMS	Digital Fortran	N/A
HP	HP-UX	HP Fortran	HP C
MAC Power PC	MAC-OS	Language Systems Fortran 3.3	Metrowerks CodeWarrior C 5.3
MAC Power PC	MAC-OS	Absoft Fortran 4.4	

Supported Platforms - 3

Hardware	Operating System	Fortran Compiler / Options	C Compiler / Options
PC	Red Hat Linux	Fort77 (f2c/gcc)	gcc
PC	Red Hat Linux 6.1+	g77	gcc
PC	MS Windows 95/98/NT	Digital Fortran, version 6	MS Visual C++/C
SGI	IRIX	SGI Fortran, N32 ABI	MIPS C, N32 ABI
SGI	IRIX	SGI Fortran, O32 ABI	MIPS C, O32 ABI
Sun	Solaris	Sun Fortran	Sun C
Sun	Solaris	N/A	gcc

Access to Toolkit and Tutorials

- Packages for all SPICE Toolkit environments are available from NAIF's anonymous ftp server:
  - ftp://naif.jpl.nasa.gov/pub/naif/toolkit/
  - Select either the FORTRAN or C directory
  - Select the environment you want (platform/OS/compiler)
  - Follow the instructions in the README file

- A set of SPICE tutorial packages is available from NAIF's anonymous ftp server:
  - ftp://naif.jpl.nasa.gov/pub/naif/tutorial/current/
  - These are available in MS Office format (and soon PDF also)
  - The file named 02_tutorials_index provides an index of the complete set of packages (see next two charts)
  - Download the tutorials using binary mode of FTP

SPICE Tutorials - 1

Index - Page 1

Tutorial Number	File Name	Length (pages)	Topic
1	readme	2	Description of these Tutorials (plain ASCII text document)
2	tutorials_index.xls	1	Index of SPICE Tutorials (MS Excel document)
3	purpose_scope	3	Tutorials Purpose and Scope
4	tutorials_intro	6	Tutorials Introduction
5	motivation	6	Motivation for Development of SPICE
6	spice_overview	18	SPICE Overview
7	concepts	47	Basic Concepts (of observation geometry, regardless of SPICE)
8	intro_to_kernels	11	Intro to Kernel Files
9	porting_kernels	11	Porting Kernels Between Computers
10	intro_to_toolkit	23	Intro to Toolkit: libraries, utilities, applications, documentation
11	metadata	8	Metadata in SPICE Kernels (use of comment area, etc.)
12	conventions	12	SPICE Conventions
13	time	10	Time: Conversions and Formats
14	spk	26	SPK (Ephemeris subsystem)
15	pck	15	PCK (Planetary cartographic constants)
16	ik	22	IK (Instrument information)
17	ck	16	CK (Orientation information)
18	fk	8	FK (Reference frames specifications)

SPICE Tutorials - 2

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